

Titan Molecular Minerals

More Abundant Than We Thought?

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50th Lunar and Planetary Science Conference

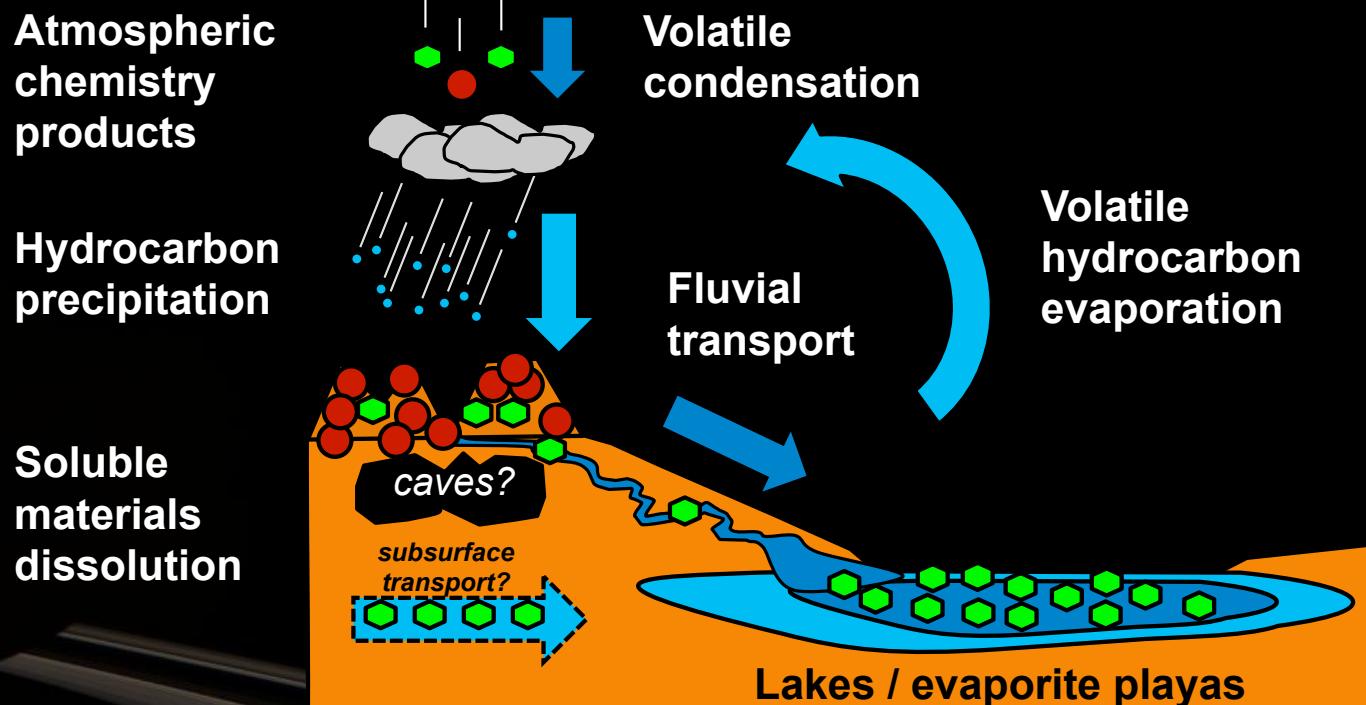
18 March 2019



Jet Propulsion Laboratory
California Institute of Technology

Titan Surface Processes

Study the pieces to understand the whole



Titan Laboratory Experiments

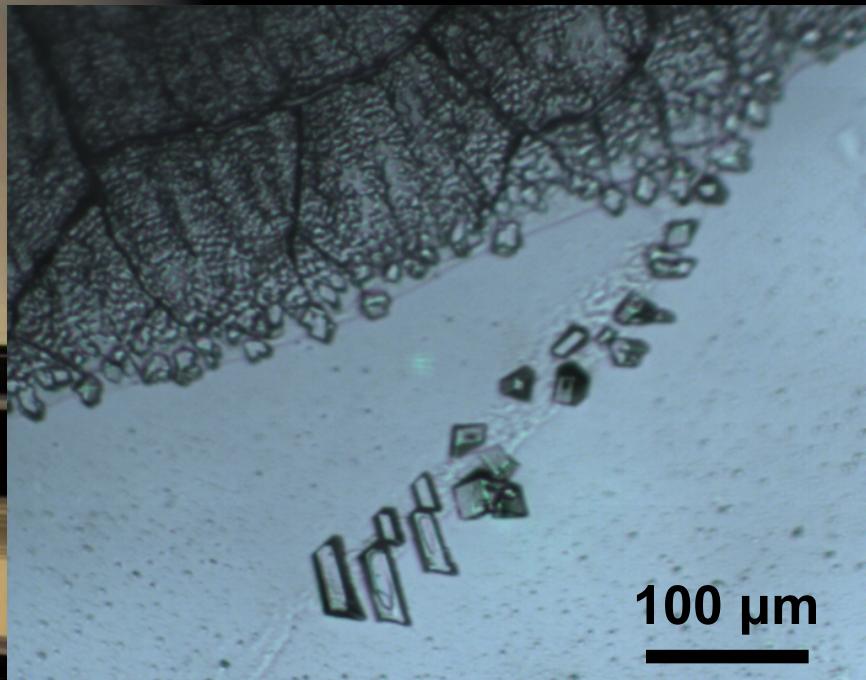
Tackling Titan's surface chemistry, one experiment at a time



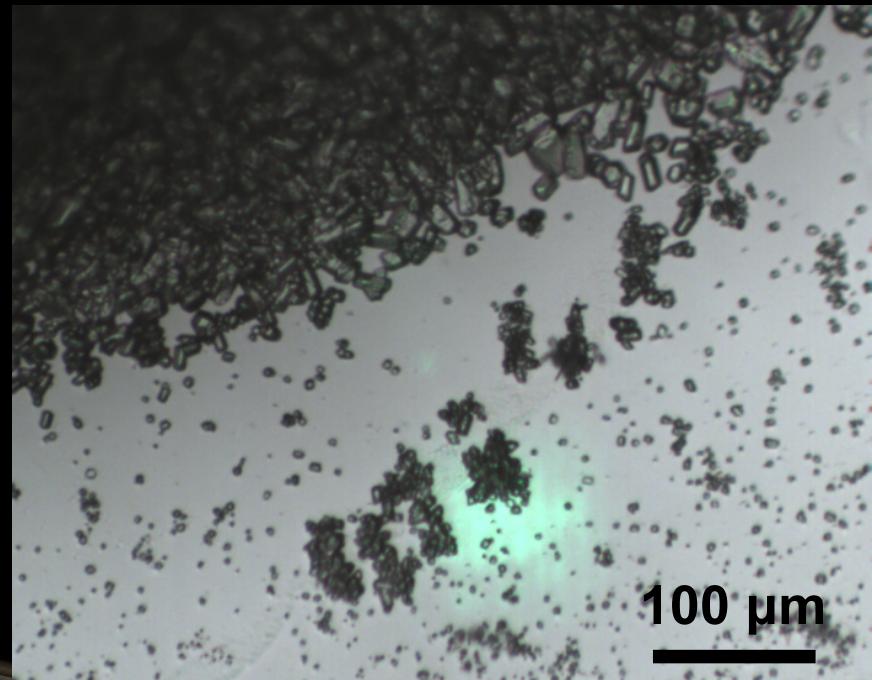
Titan Laboratory Experiments: Benzene and Ethane

Recrystallization occurs when benzene and ethane are mixed

Before



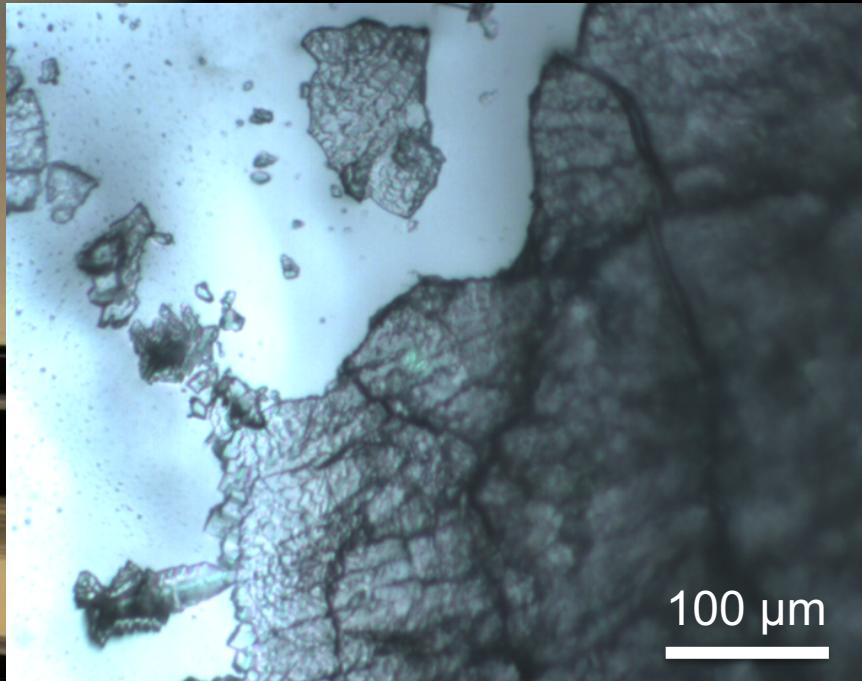
After 15 minutes



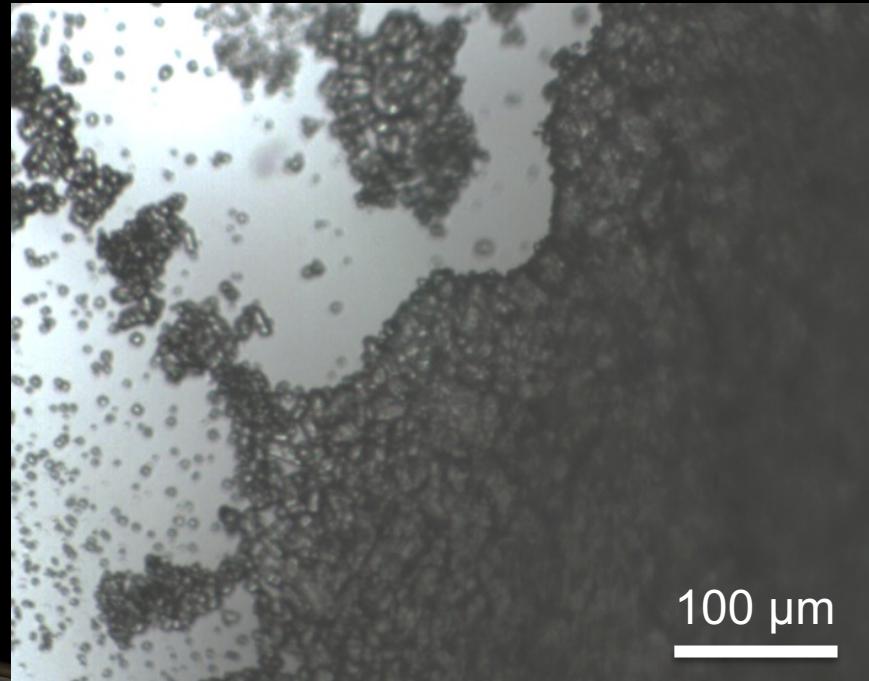
Titan Laboratory Experiments: Benzene and Ethane

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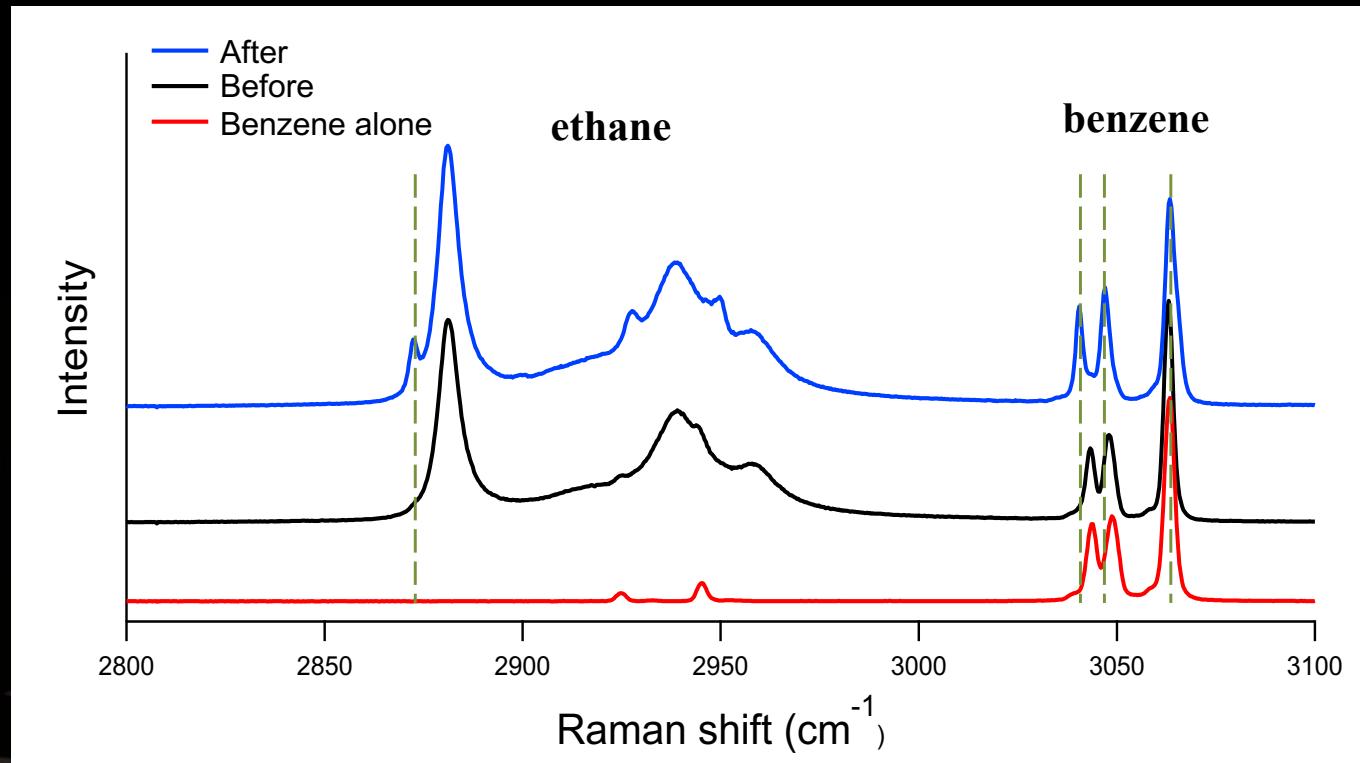


After 15 minutes



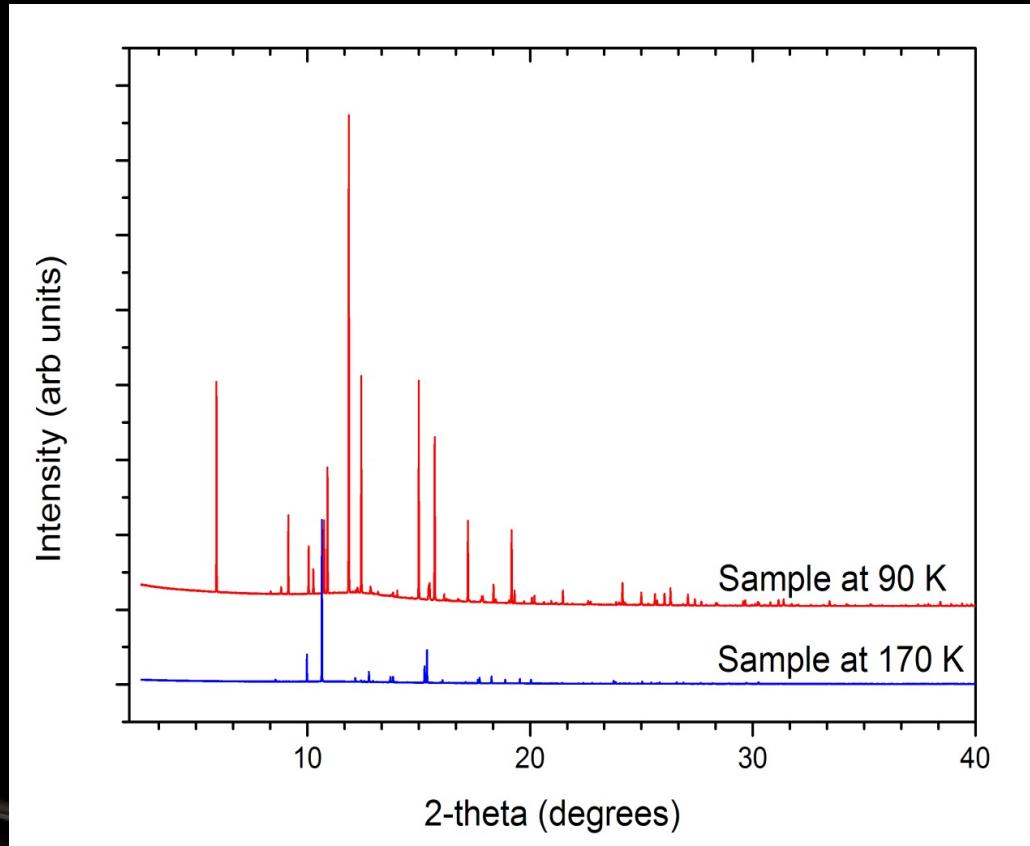
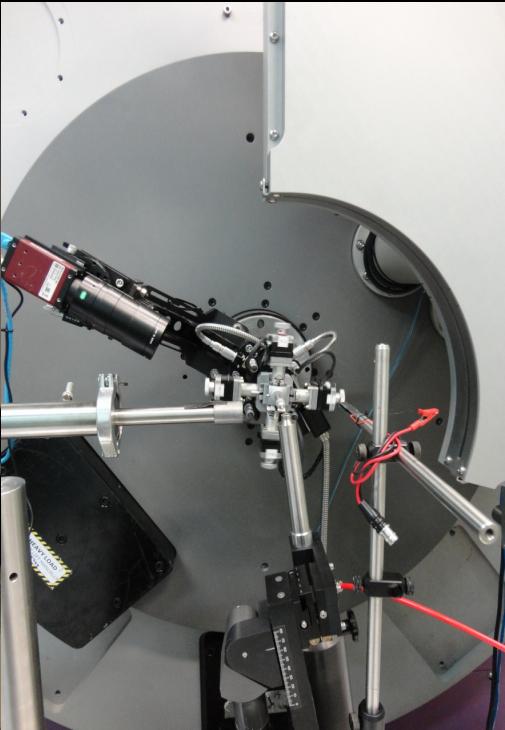
Titan Laboratory Experiments: Surface Deposits

Recrystallization occurs when benzene and ethane are mixed



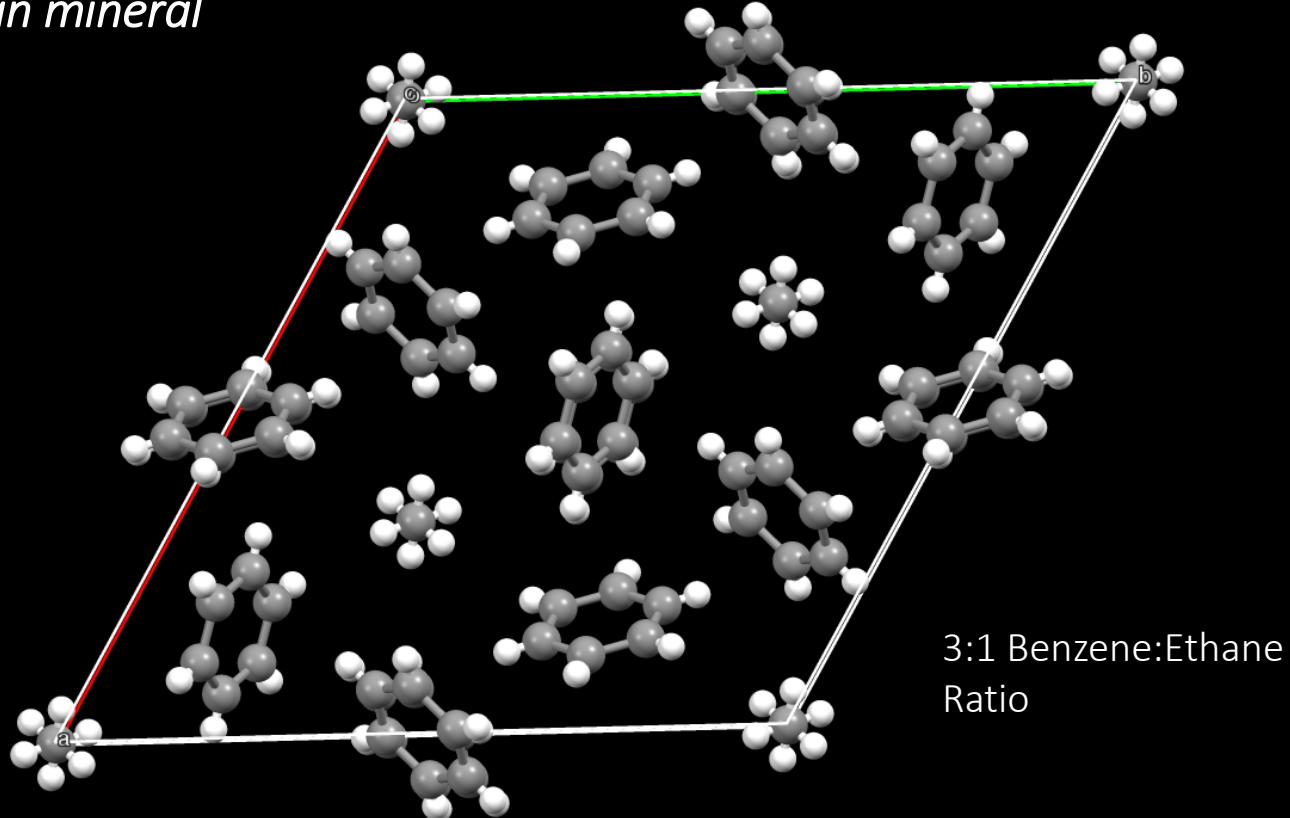
Benzene and Ethane

Cryogenic X-ray diffraction



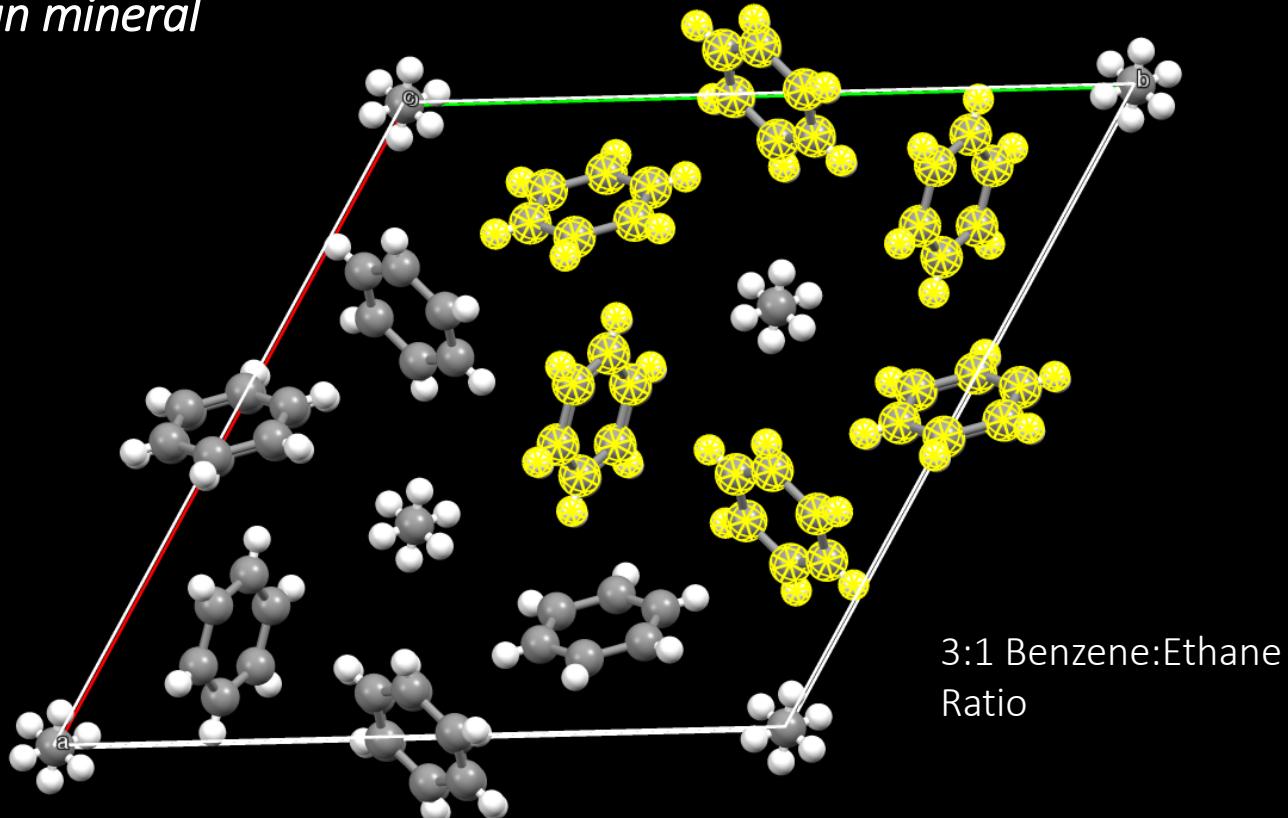
Benzene Ethane Co-Crystal

The first discovered Titan mineral



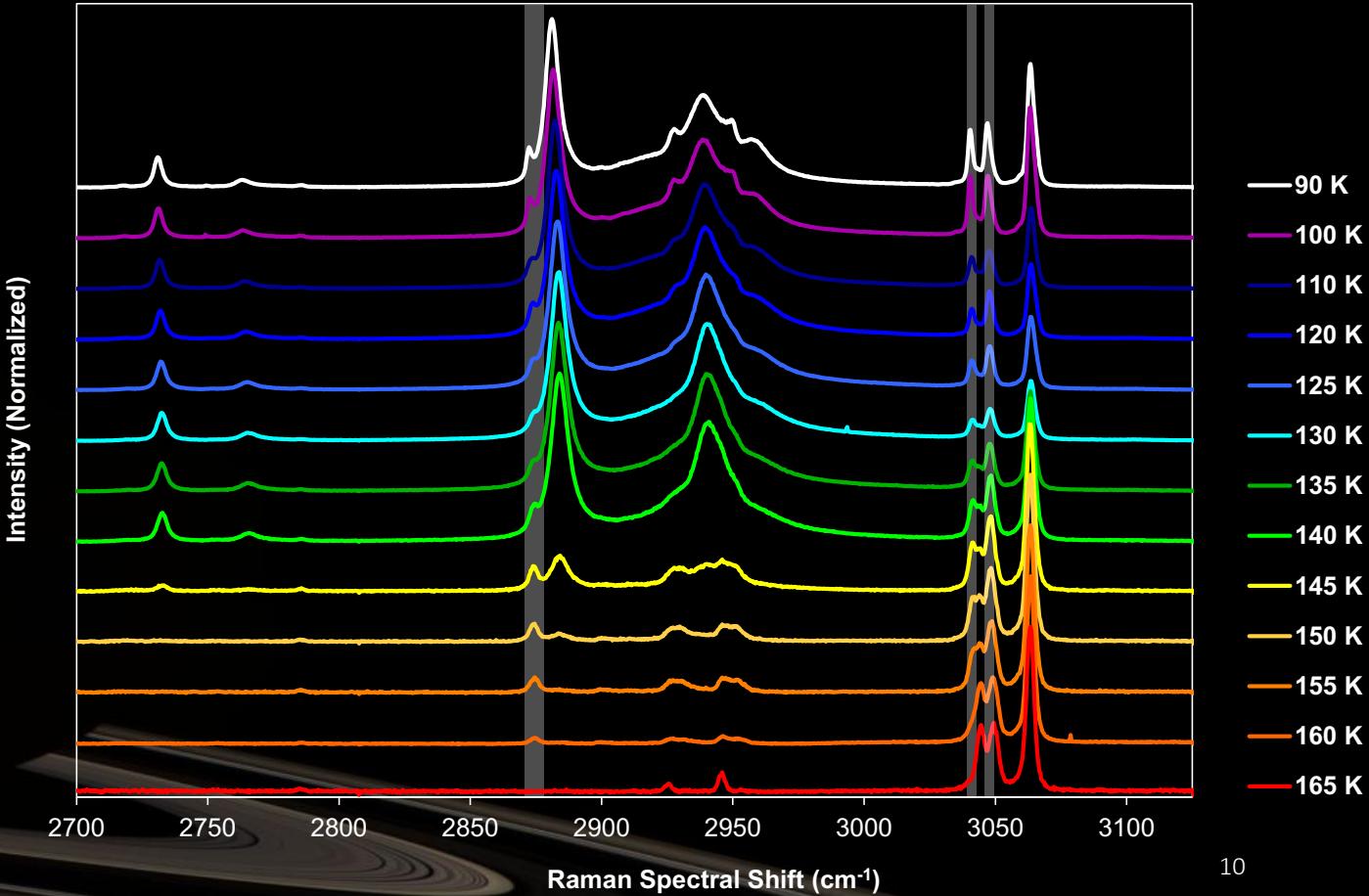
Benzene Ethane Co-Crystal

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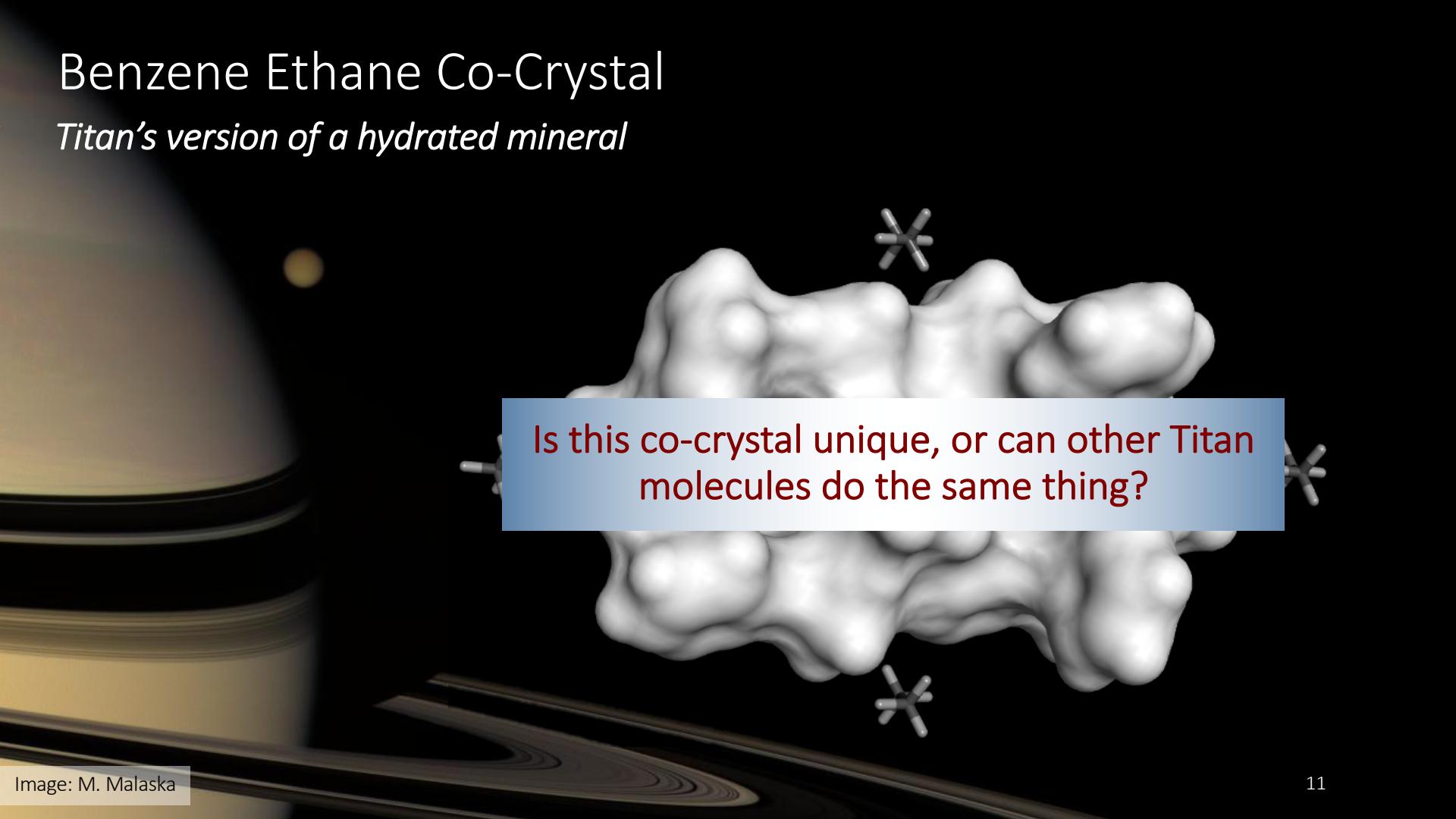
Benzene Ethane Co-Crystal

Stable up to 165 K



Benzene Ethane Co-Crystal

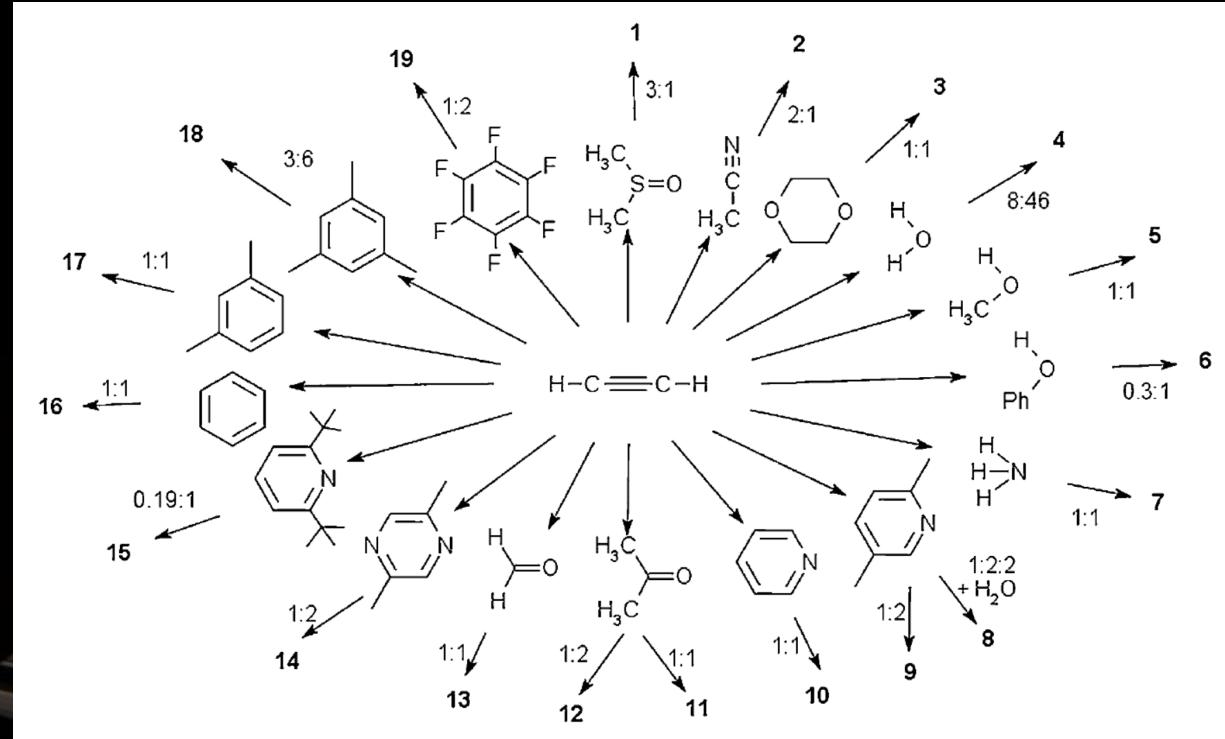
Titan's version of a hydrated mineral



Is this co-crystal unique, or can other Titan molecules do the same thing?

Acetylene Loves to Form Co-Crystals

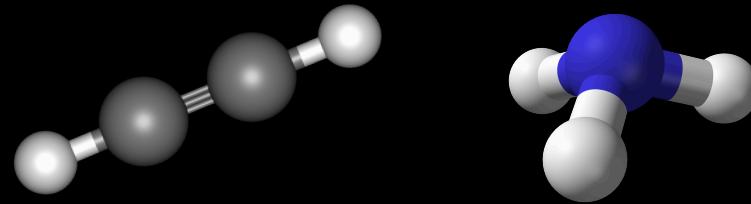
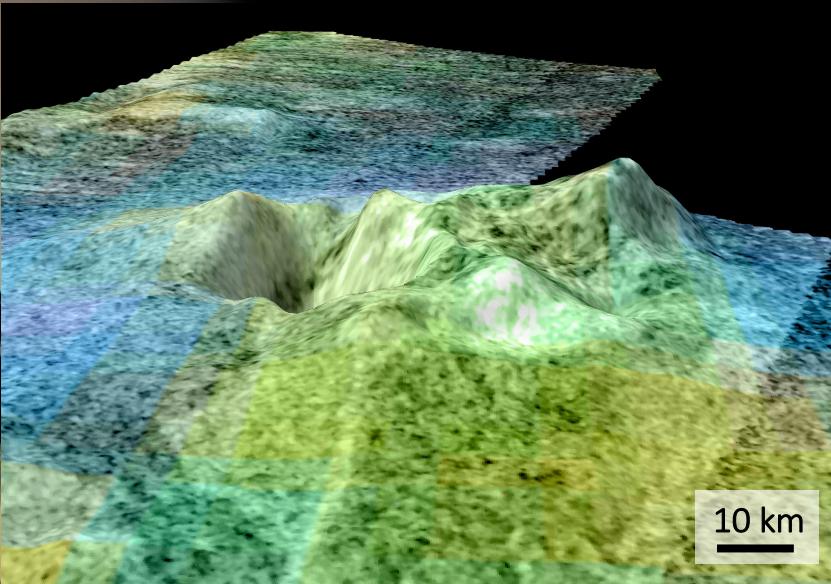
Can acetylene form co-crystals under Titan-like conditions?



Acetylene and Ammonia

Another co-crystal?

Evidence of Cryovolcanism



- Acetylene is one of the most abundant solids produced via photochemistry on Titan
 - Detected in the atmosphere by INMS¹ and on the surface by Huygens GC-MS²
- Ammonia may also exist on Titan's surface today
 - The origin of Titan's nitrogen-rich atmosphere is most likely ammonia ice^{1,3}
 - Mixing could occur via cryovolcanism or other surface processes^{4,5}

1) Waite et al., 2005, *Science*, 308, 982-986.

2) Niemann et al., 2010, *JGR*, 115, E12006.

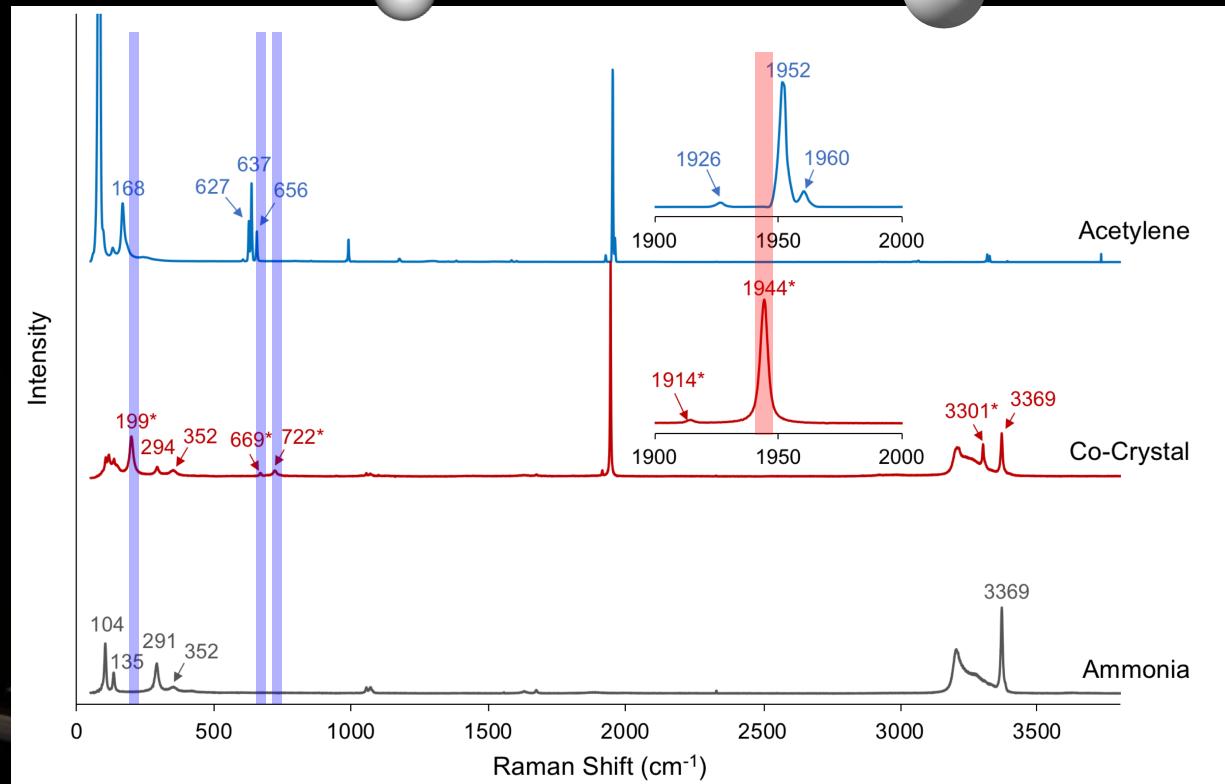
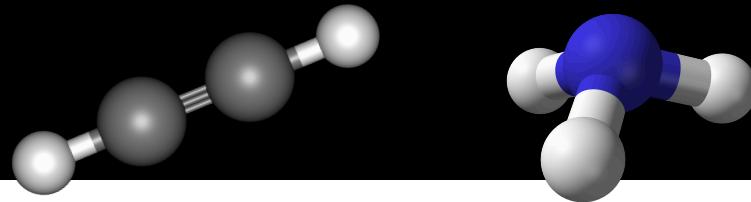
3) Mandt et al., 2014, *Astrophys. J. Lett.*, 788, L24, 1-5.

4) Lopes et al., 2013, *JGR*, 118, 416-435.

5) Nelson et al., 2009, *Icarus*, 199, 429-441.

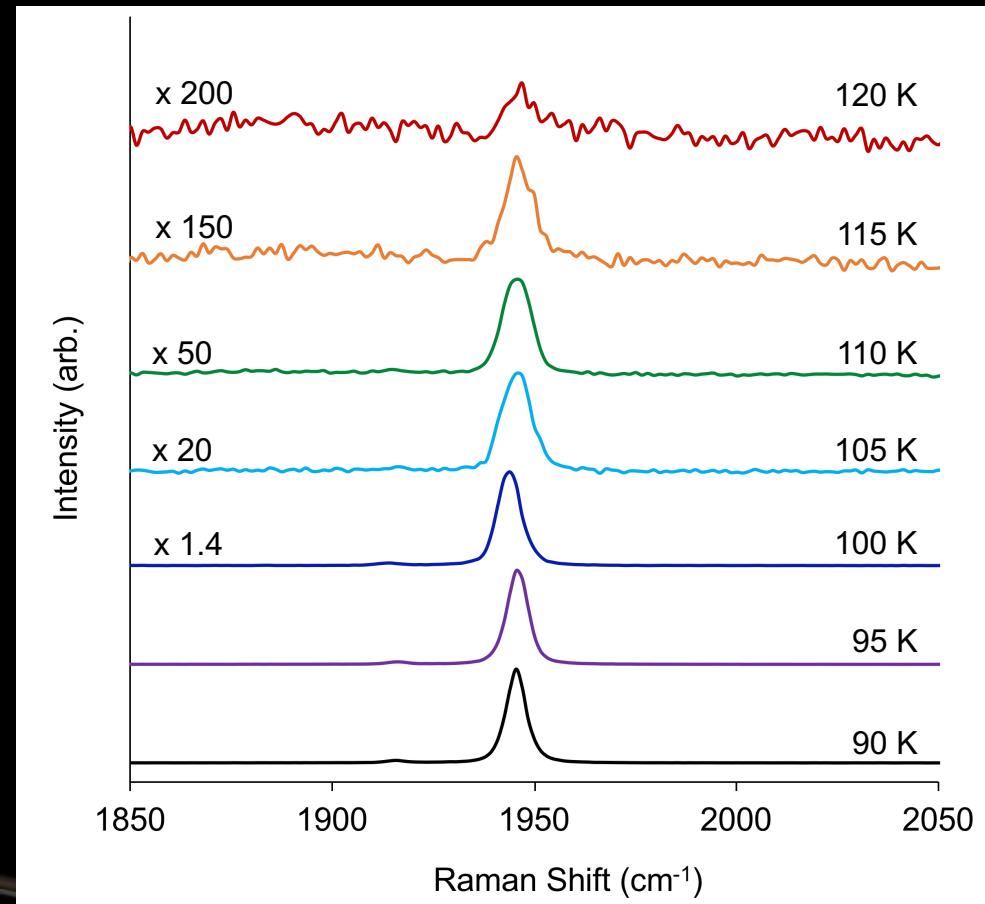
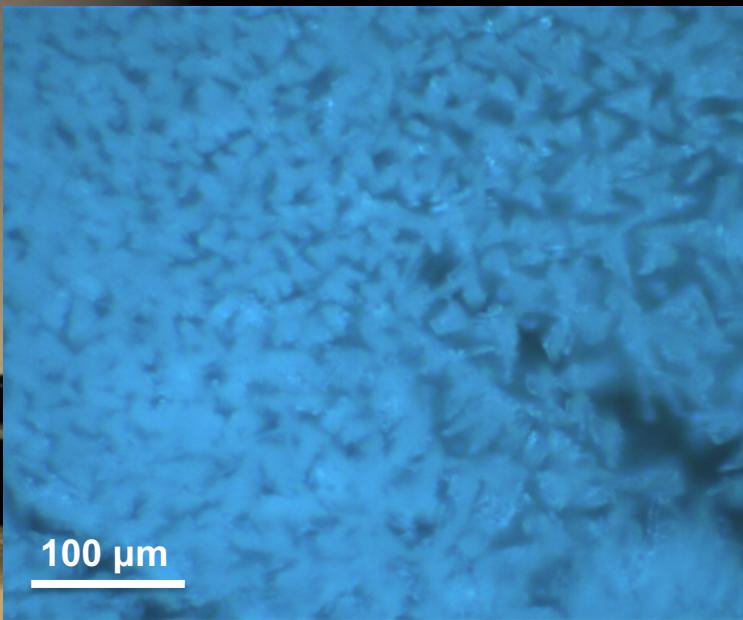
Acetylene and Ammonia

New features in Raman



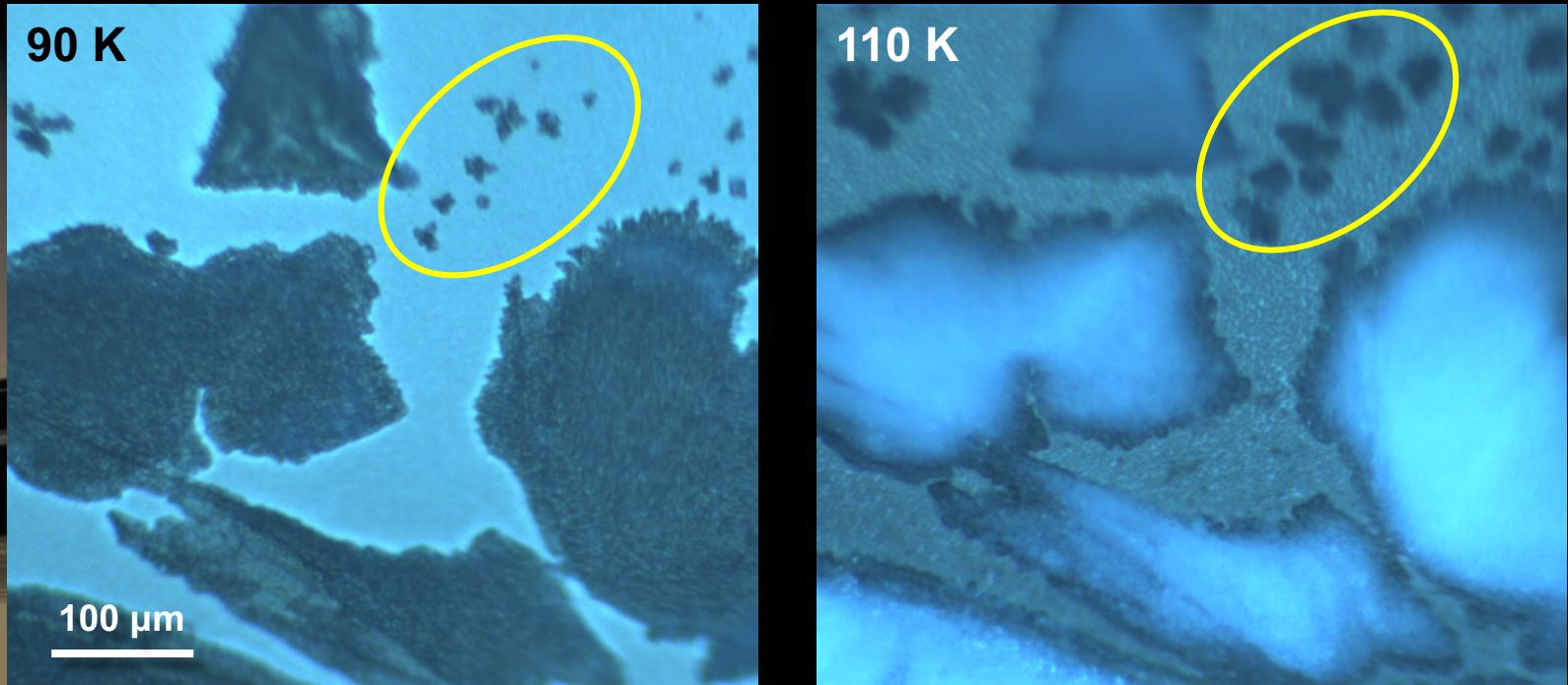
Acetylene and Ammonia

Co-crystal is stable up to 115 K



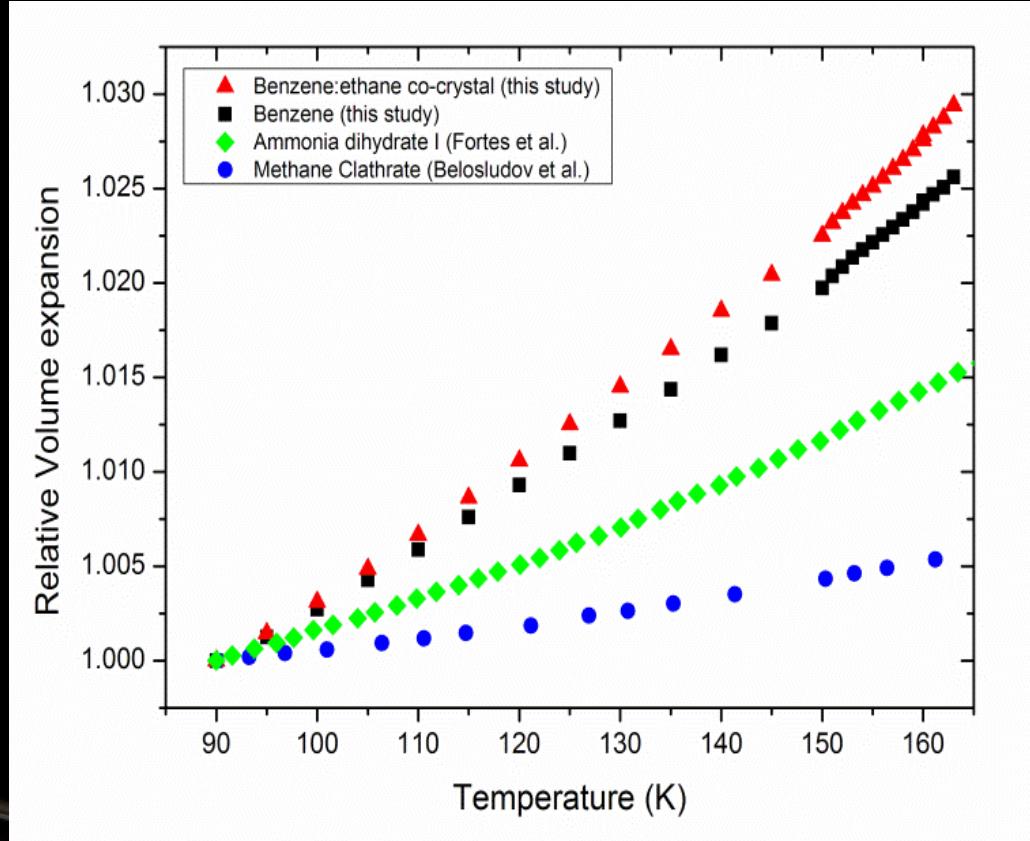
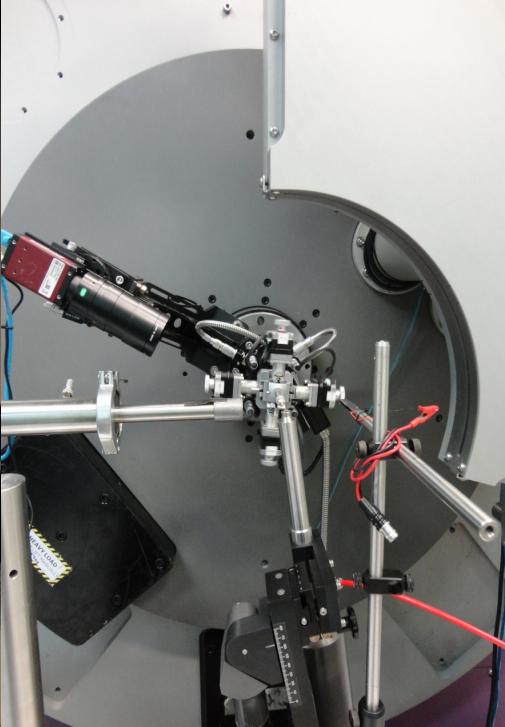
Acetylene and Ammonia

Evidence for expansion of the co-crystal upon heating



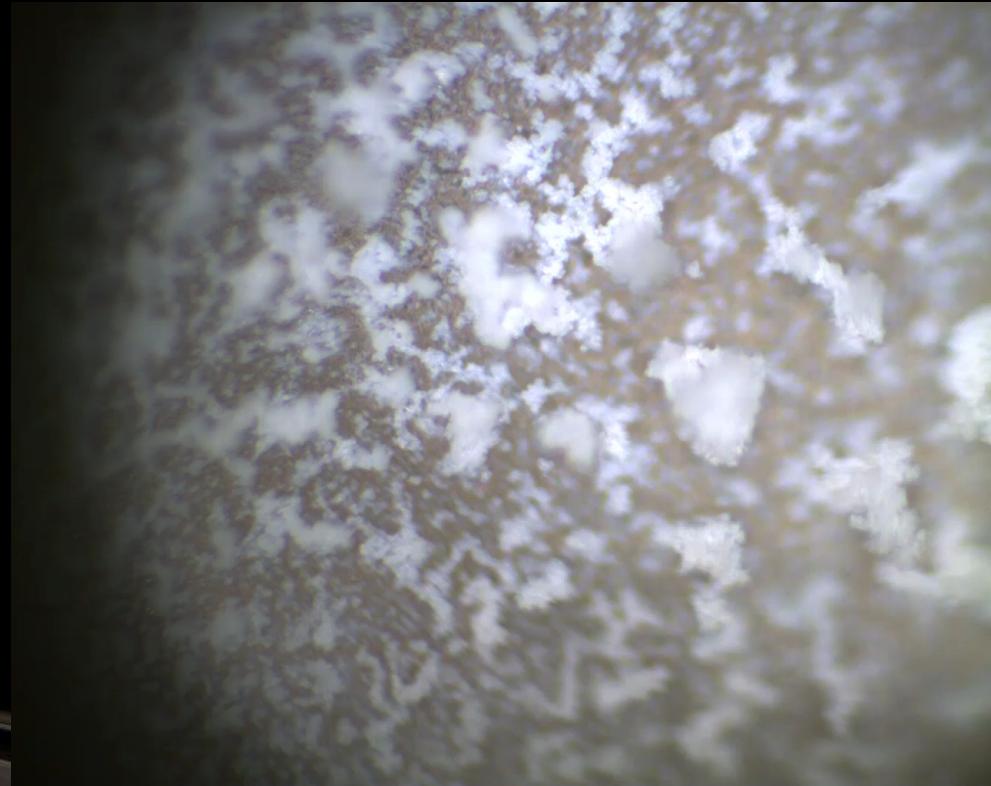
Benzene and Ethane

High thermal expansion



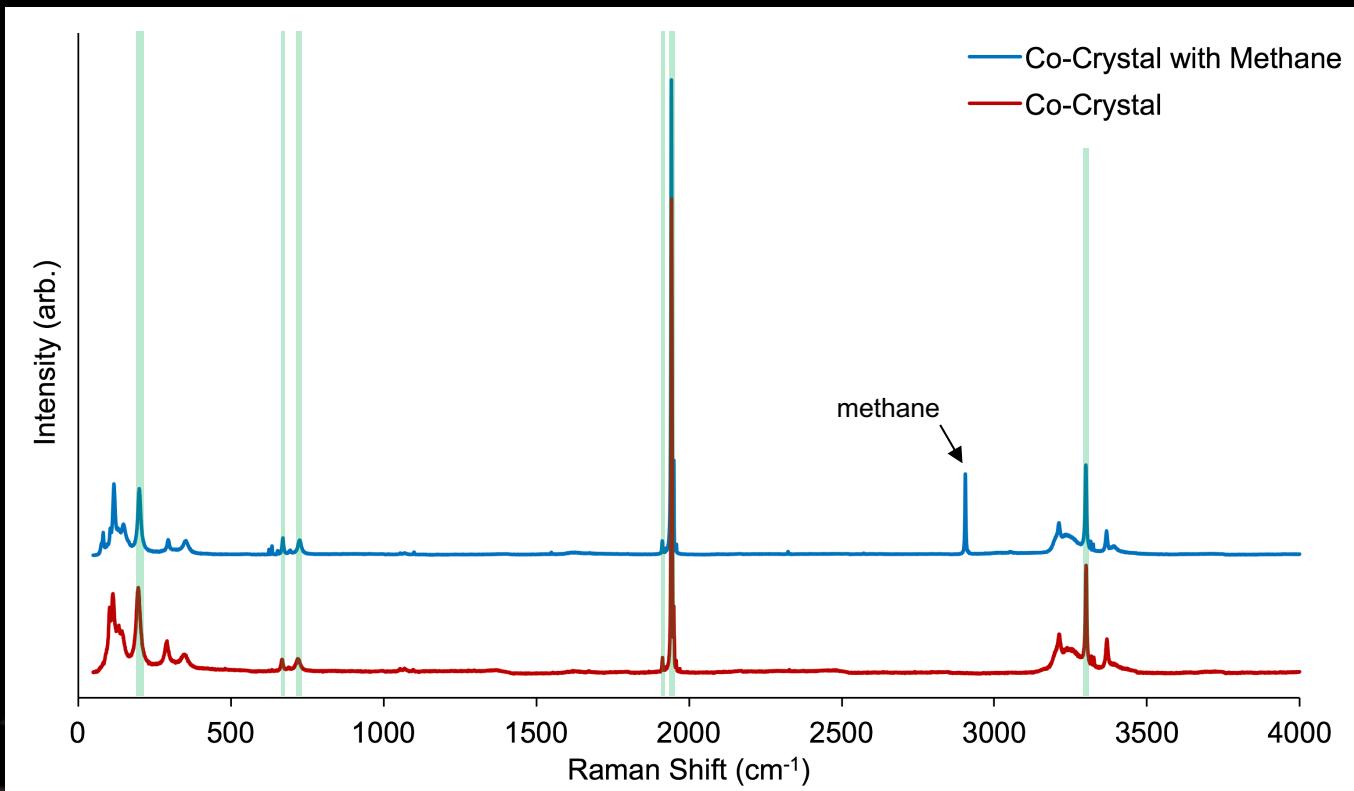
Acetylene and Ammonia

Stable when exposed to hydrocarbon fluvial and pluvial events



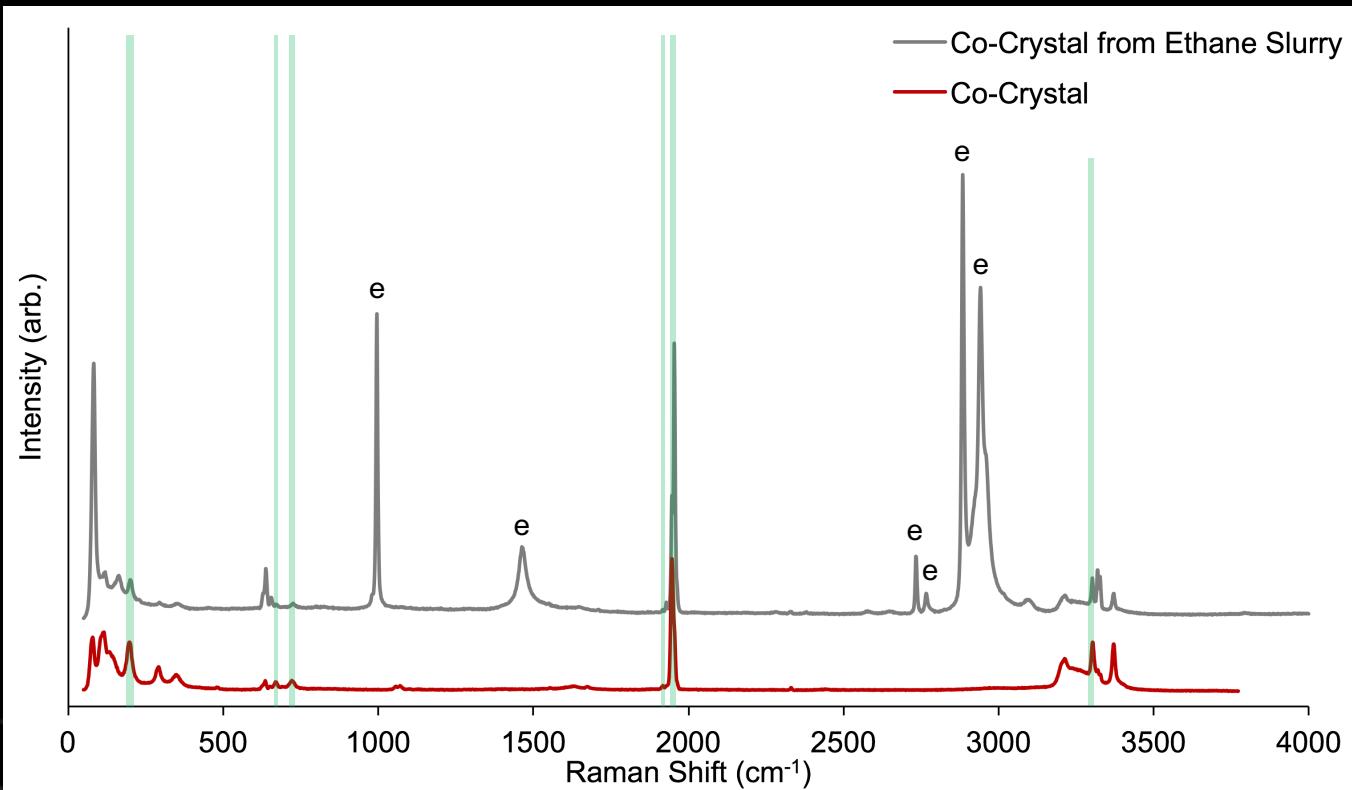
Acetylene and Ammonia

Stable after methane pluvial event



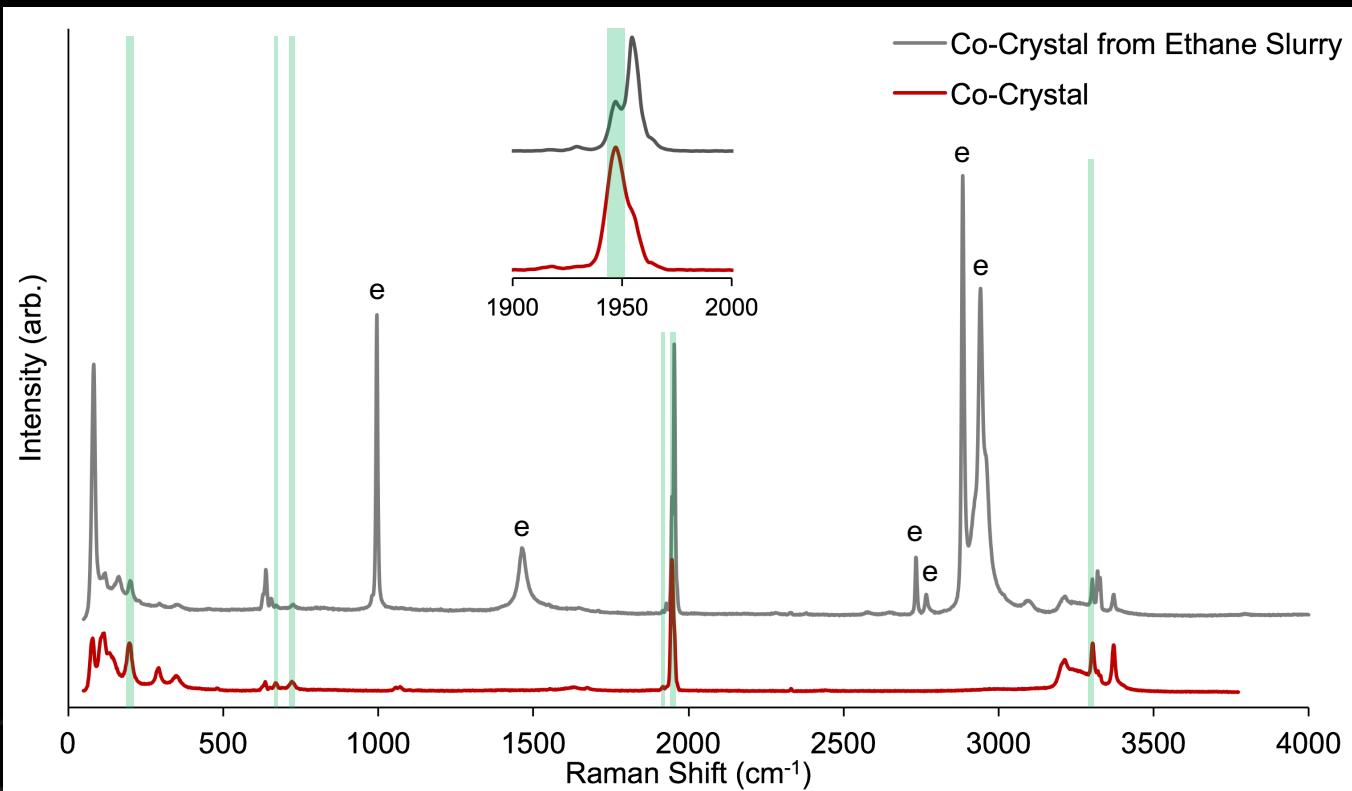
Acetylene and Ammonia

Co-crystal forms from acetylene-saturated ethane fluvial event onto solid ammonia



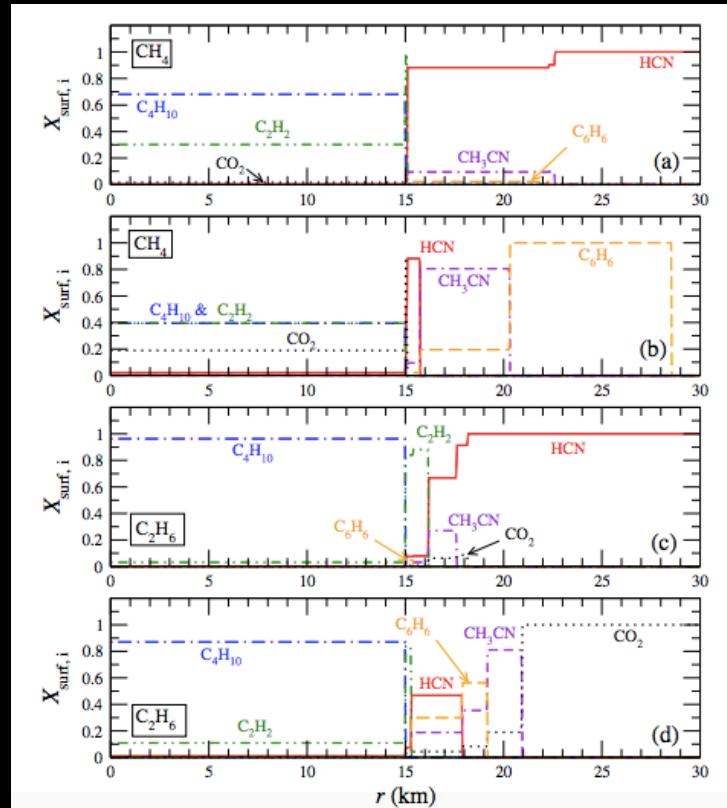
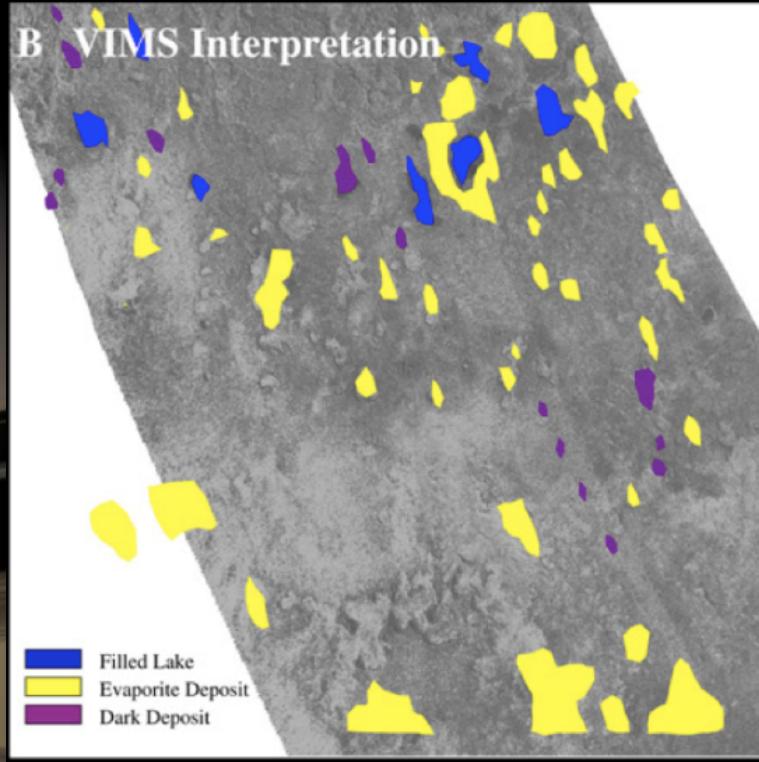
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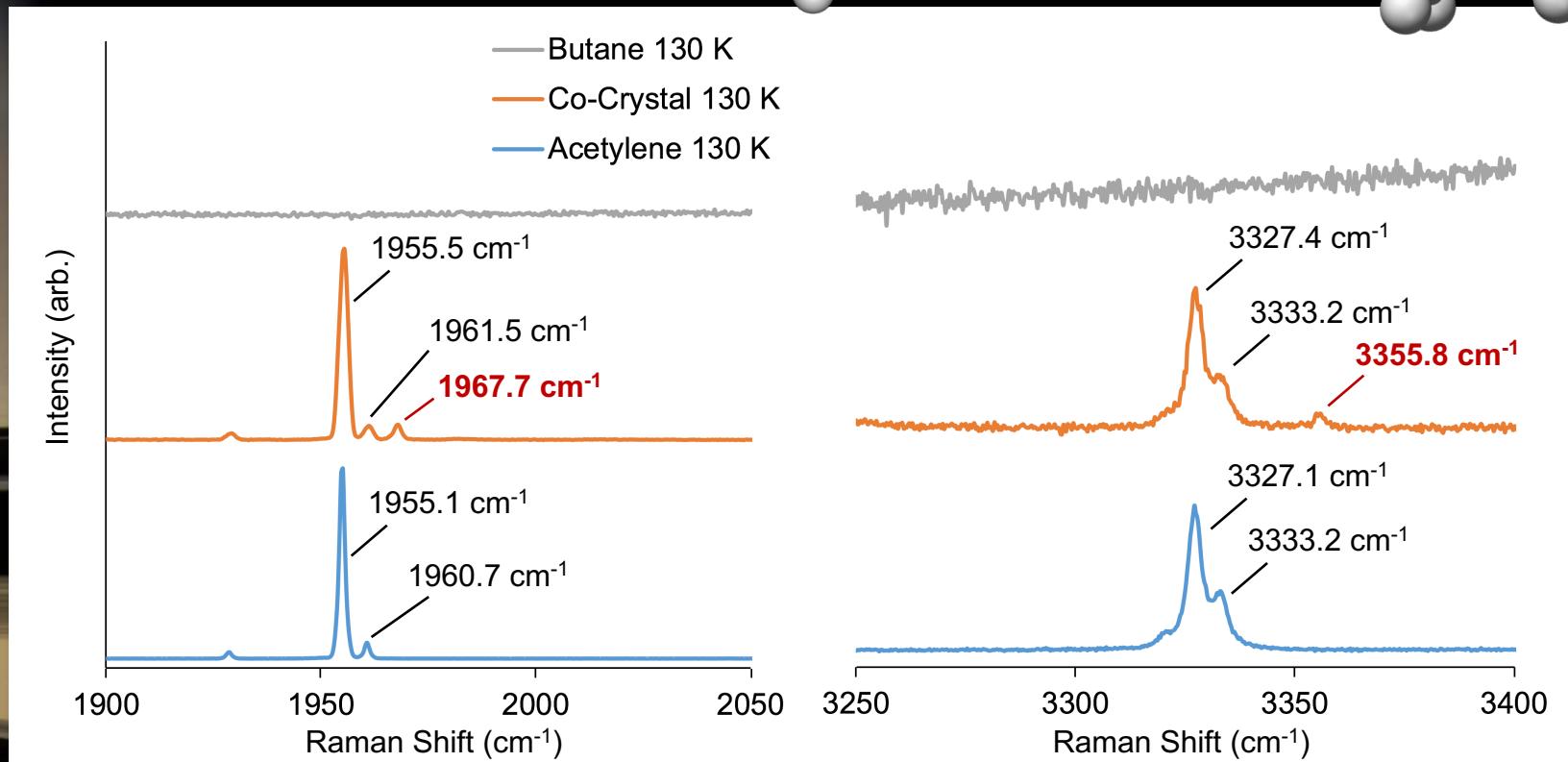
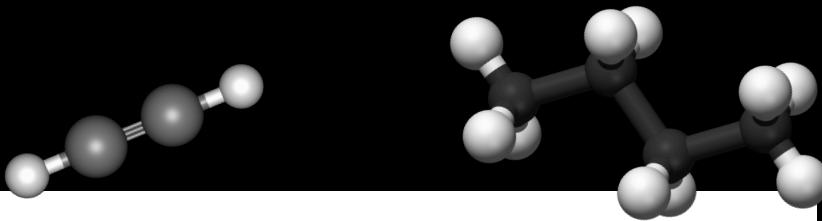
The Search for a New Co-Crystal

Back to the basics: Bathtub rings



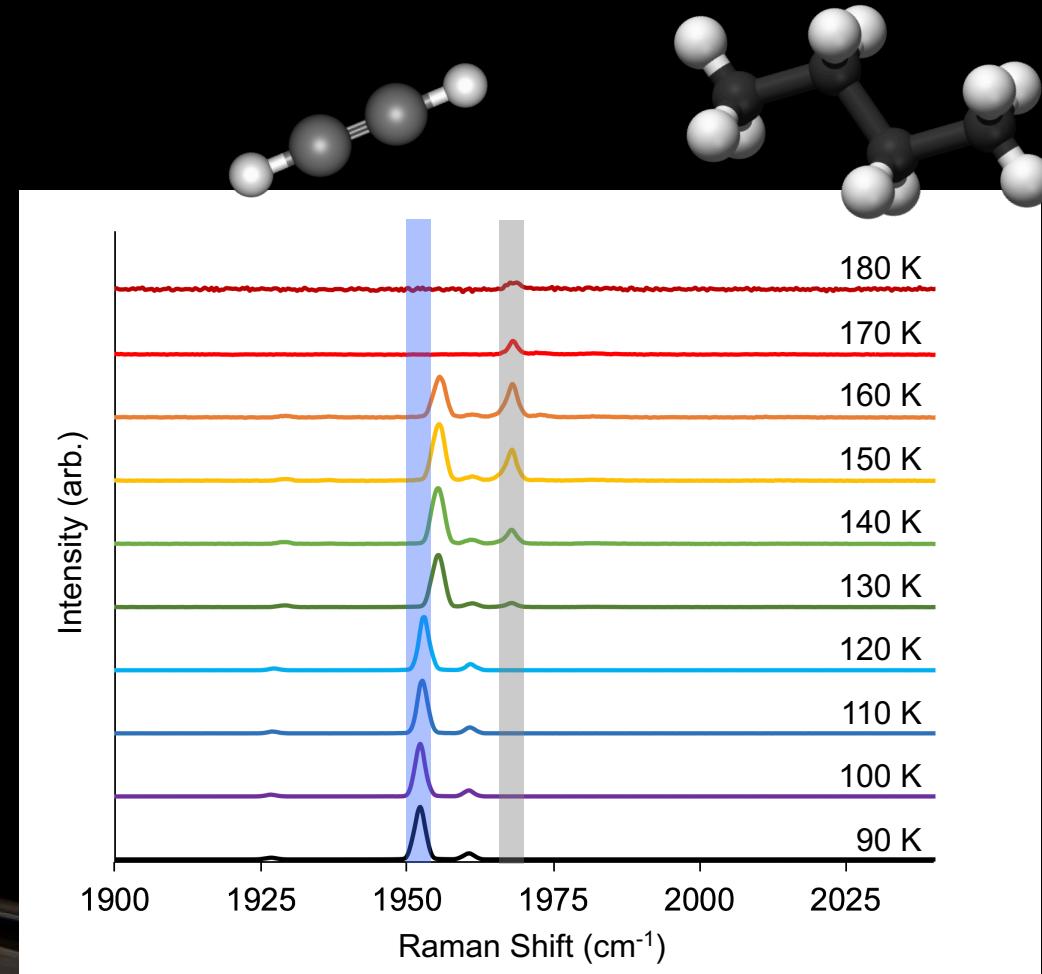
Acetylene and Butane

An abundant co-crystal?



Acetylene and Butane

Stable up to 180 K



Titan Laboratory Experiments: Conclusions

Learning what makes Titan tick

- A third co-crystal has been confirmed between acetylene and butane; it forms readily at 130 K, the same temperature where butane melts and acetylene exhibits a phase transition.
- Organic co-crystals may be abundant on Titan, and may assume the role of minerals on Earth.
- Co-crystals may be responsible for surface material characteristics such as particle size, dissolution rate, structural hardness, and resistance to erosion.
- Differences in physical or mechanical properties may also lead to chemical gradients, which life could potentially exploit.

Acknowledgements

Thanks to all the “Titan-ium Rock Stars”



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- Tuan Vu
- Mike Malaska
- Helen Maynard-Casely
- Mathieu Choukroun
- Pat Beauchamp
- NASA Astrobiology Institute
- NASA Solar System Workings
- Australian Nuclear Science and Technology Organisation

Backup

Acetylene and Ammonia

Potential mechanisms for interaction of acetylene and ammonia on Titan

